

A Procedure for Estimating Cloud Amount and Height From Satellite Infrared Radiation Data

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ABSTRACT—A simple objective technique is presented that integrates satellite-measured infrared radiation temperatures with the National Meteorological Center objective temperature analysis to yield cloud height and amount classification for small grid squares. Samples of cloud information obtained by this technique from ITOS 1

data over the United States show good agreement with cloud observations obtained by surface observers and from aircraft reports. The method is completely automated and can be used to produce cloud analyses on a global scale.

1. INTRODUCTION

Over the past several years, several satellites equipped with infrared radiometers sensing in the "window" region of the infrared (IR) spectrum have been in operation. The most recent of these were the ITOS 1 and NOAA 1 satellites with scanning radiometers sensing in the 11- μ m window, and the Nimbus series with a high resolution radiometer sensing in the 3.5 to 4.1- μ m and 10- to 11- μ m spectral regions. Data with less resolution were used in the past to locate clouds and to estimate heights (e.g., Fritz and Winston 1962, Rao and Winston 1963).

The technique presented here is an attempt to use ITOS 1 data objectively to obtain cloud amounts and heights. The major impetus for this study arises from the need to present to the field user a stable interpretation of the thermal imagery consistent with the capability of his equipment to preserve the information transmitted. To this end, we have developed a grid-print-type output and a product that relies on reproducing only four gray levels of information on a facsimile-type device. It is felt that products of this type best preserve the information that can be received currently at most field stations.

The data used for this study were the Northern Hemisphere polar stereographic mosaic maps of equivalent blackbody temperatures (data acquired at 0300 LST) with a resolution 32 times that of the National Meteorological Center (NMC) mesh (12 km at 45°N), and the NMC-analyzed temperature fields at the surface, 700 mb, and 400 mb. The pressure levels were chosen to approximate low, middle, and high clouds, respectively. The infrared-sensed temperature was used under the assumption that the clouds are opaque; this assumption is not always true, especially with cirriform clouds, and can, therefore, result in errors of interpretation. Clouds of uniform height that do not cover the entire field of view also present difficulties. These factors are discussed in greater detail later.

2. GRIDPRINT MAP

The amount of cloud between pressure levels is computed for each NMC grid square by first constructing a histogram from the IR data contained in the grid area under consideration (32×32 or 1,024 IR spots). This histogram represents the distribution of temperatures within the grid area. The NMC temperature field is then queried for the class intervals appropriate to segment the histogram into four temperature classes. An example is shown in table 1. There, T_{IR} is the satellite IR brightness temperature, and T_{stc} , T_{700mb} , and T_{400mb} are the NMC temperatures in °C at the surface, 700 mb, and 400 mb. The subtraction of 5°C from the surface temperature is used to insure that the earth surface view is not included as low clouds. In this classification scheme, it was assumed that clouds are completely opaque and radiation emanates from the cloud tops. Therefore, each cloud height category signifies that the tops of the clouds lie within that layer or above.

Figure 1 is a histogram of IR data with the NMC temperature class boundaries included. In this example, 3/8 of the data spots fell within the temperature range defining low clouds, 2/8 in the middle cloud range, and 1/8 in the high cloud range. The above procedure is followed for all the gridpoints in the NMC octagon and the results are then displayed as in figure 2A. The computed cloud information for each of the gridpoints in the sample area of figure 2A is displayed as a three-digit number adjacent to the gridpoint indicated by a +. For example, +341 represents 3/8 high cloud, 4/8 middle cloud, and 1/8 low cloud. Occasionally, the total cloudiness will exceed 8/8 because of roundoff error in the processing of the data.

In this case for Mar. 22, 1971, we have outlined the high-cloud areas, which we feel might present the most trouble, and compared them to the surface observations and pilot reports (PIREPS) in figures 2B and 2C. We observe good large-scale agreement in the northwestern United States, the Appalachians, and Central Mexico;

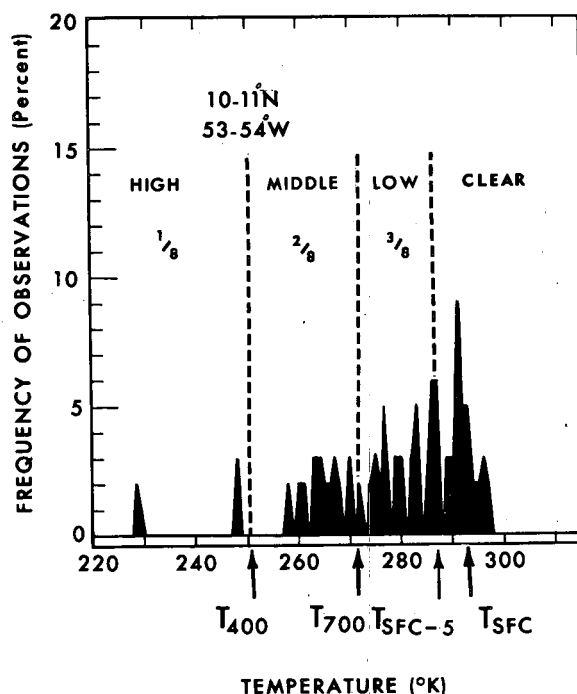


FIGURE 1.—Sample histogram showing the frequency of observed temperatures (from ITOS 1) and the cloud amount-type classification.

TABLE 1.—Cloud classification based on NMC temperature intervals

NMC temperature interval	IR data classification
$T_{IR} \geq (T_{sfc} - 5^\circ C)$	No clouds
$(T_{sfc} - 5^\circ C) > T_{IR} > T_{700mb}$	Low clouds
$T_{700mb} \geq T_{IR} \geq T_{400mb}$	Middle clouds
$T_{400mb} > T_{IR}$	High clouds

however, the thin cirrus observed over portions of Texas and New Mexico has not been detected. Some of the differences between the observations may be caused by the differences in verifying times of the data. The satellite data were composited from three separate orbital passes over a 4-hr time period.

3. PICTORIAL DISPLAY

The procedure for displaying pictorially the estimates of cloud amount and cloud top height closely follows the procedure used for the formation of the gridprint map. However, the original resolution of the IR data is retained in this presentation. The category of each individual IR brightness temperature is selected using the NMC temperature intervals specified earlier. Each category is then assigned one of four gray shades. The replacement table is recomputed with the correct temperature intervals for each NMC grid area. To suppress abrupt discontinuities in the gray shade display, we used a two-dimensional smoothing algorithm on the NMC temperature field. The converted data are then displayed by a photo-

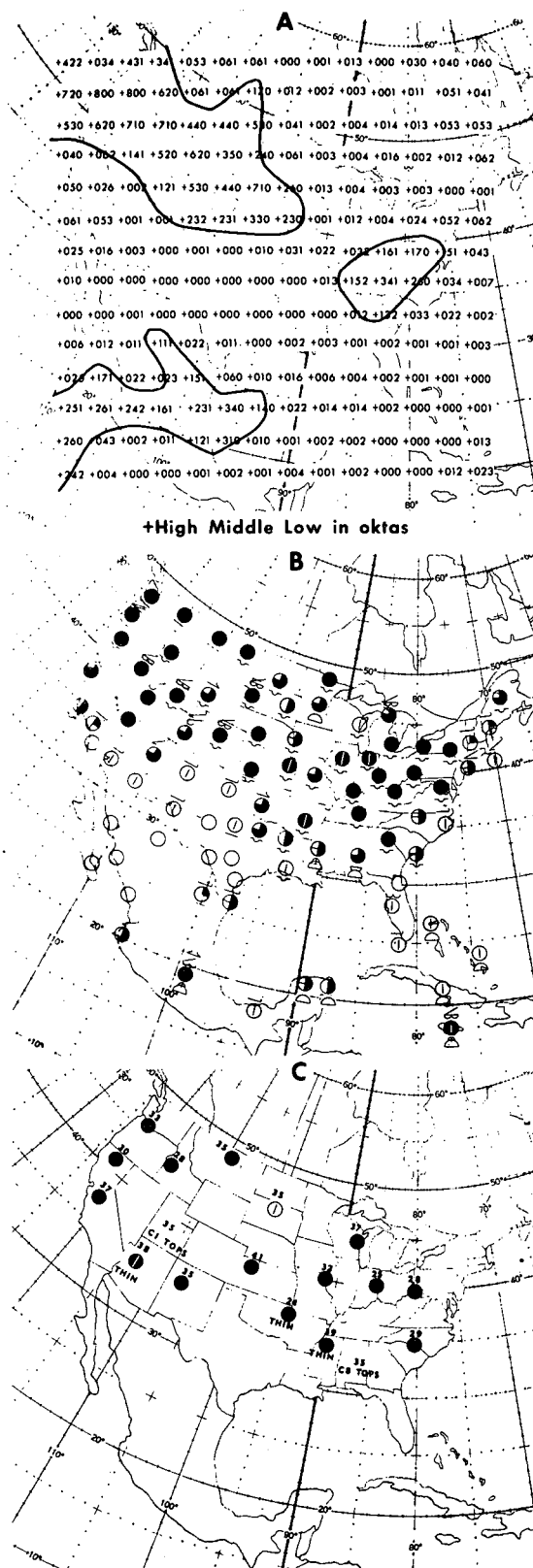


FIGURE 2.—Gridpoint display of the cloud type and amount obtained from (A) ITOS 1 IR data, (B) surface observations, and (C) significant weather information from aircraft reports. (Aircraft report cloud tops in thousands of feet.)

graphic device to form the cloud amount and cloud-type imagery shown in figure 3A.

Figure 3B shows the conventional display of the IR

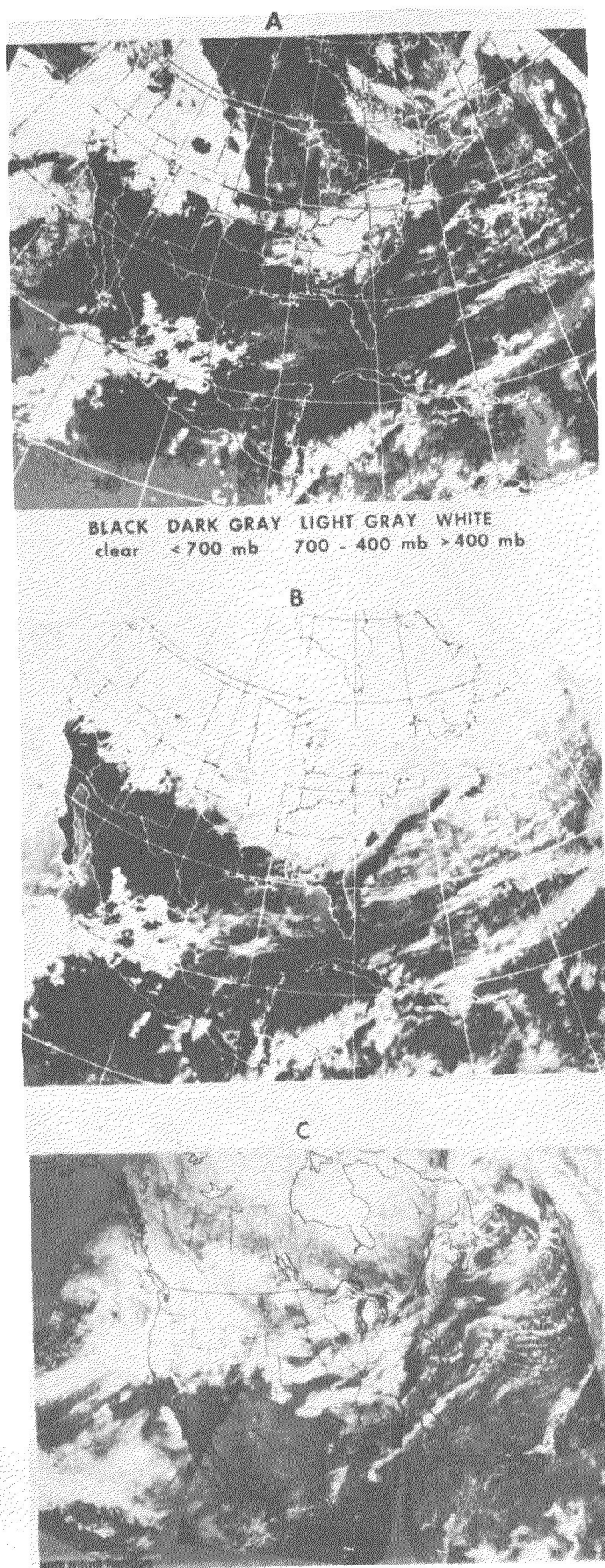


FIGURE 3.—Pictorial display of the cloud-type information obtained from (A) ITOS 1 satellite IR data, (B) conventional IR, and (C) APT.

data and figure 3C shows a mosaic of the pictures obtained by automatic picture transmission (APT) 6 hr earlier than the IR. The conventional display uses a gray scale that varies with latitude; this variation is based on climatologically derived zonal mean temperatures. The method under discussion here uses synoptic temperature fields updated every 12 hr. In comparing the three images, we see that the cloud-type imagery of figure 3A has separated the clouds from the snow and ice in the northern United States and Canada. This method also results in differentiation between the high and the middle clouds in figure 3A; this information is lost in the other imagery.

4. PROBLEM AREAS

The problems with thin cirrus have been examined by Fritz and Rao (1967). Figure 4 (Jacobowitz 1970) shows the theoretical transmissions in the $11\text{-}\mu\text{m}$ window for two different thicknesses of cirrus at two different levels. It is immediately apparent that cloud altitude has no significant effect on transmissivity. Because the average ice concentration observed in cirrus clouds is $0.01\text{ g}\cdot\text{m}^{-3}$, cirrus cloudiness with a thickness of almost 5 km is required to assure a reasonably accurate temperature reading. As in the case presented here, our experience shows that most major cirrus fields are positioned correctly with respect to height, but the thin trailing edges of cirrus are most troublesome to locate and are often missed as clouds entirely. Perhaps the best way to interpret the classified cloud data would be to say, for example, that the clouds viewed are above 700 mb rather than to specify that they lie exactly within the 700- to 400-mb layer.

Other IR data interpretation problems are caused by the existence of an isothermal or near-isothermal atmosphere or by the existence of inversions over the area under examination. When these atmospheric conditions prevail, a particular IR temperature measurement may not be unique to one pressure interval. In practice, the IR temperature measurement is assigned to the lowest pressure layer meeting the temperature criteria. Since such broad pressure intervals were chosen here, errors of this kind are kept to a minimum.

Errors introduced by discrepancies in time between the NMC and IR data can be expected to be negligible, particularly over oceanic regions. Significant errors may be introduced, however, in cases where rapid atmospheric changes are taking place. If standard observations could be furnished coincident in time with satellite IR measurements, these problems would be eliminated.

The assumption that the earth's actual surface temperature is constant over the area of a grid square, and equivalent to the NMC-supplied earth surface temperature, is in most cases a valid one, particularly over the oceans. However, this assumption breaks down in areas of highly variable terrain and in areas where coastlines intersect grid squares. The errors produced are reflected in the calculation of low-cloud amount. A higher resolution objective analysis would reduce these errors.

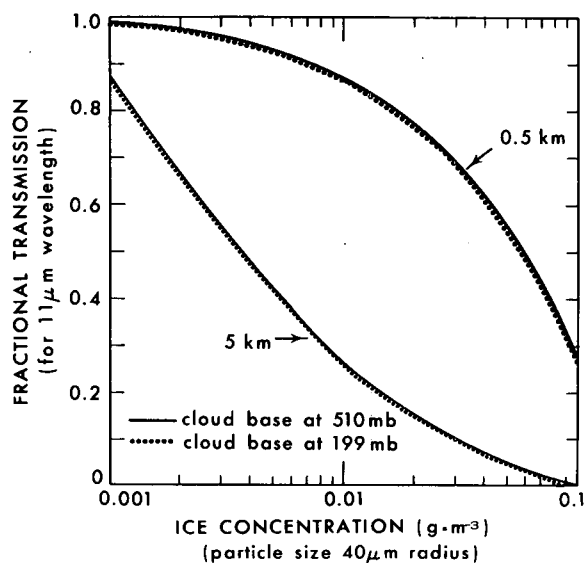


FIGURE 4.—Transmission of 10.5- to 12.5- μ m radiation through cirrus clouds having different thicknesses, heights, and ice concentrations.

No attempt was made to correct for the inherent tendency to overestimate cloud amount when using satellite data. Shenk and Salomonson (1971) described the errors in cloud amount estimation as a function of cloud element size and satellite sensor resolution. When cloud element size is near or below the sensor resolution, errors in cloud amount determinations became large. If the scanning radiometer field of view is filled with a combination of cloud and ground, the temperature sensed is some value between that of the earth's surface and that of the cloud top. Therefore, a combination of cloud-ground view results in an IR temperature retrieval colder than that of the earth's surface but warmer than that of the cloud top. This characteristic has the effect of moving all such data toward the cloud portion of the IR data histogram, causing overestimations of total cloud amount and underestimations of cloud top heights. Errors in computed cloud amount, for example, can be expected over areas of fair weather cumulus typical of oceanic regions. Overestimation is at a minimum over areas of large-scale continuous cloud cover.

The lack of an objective analysis precludes the application of the IR-NMC data meshing method, in its present form, to Southern Hemisphere-mapped IR data. Rao (1970), however, demonstrated the feasibility of building a model atmosphere from sea-surface temperature estimates generated from satellite IR data (Smith

et al. 1970), and for using these vertical temperature profiles to interpret the thermal imagery. Such a technique would be well suited for the Southern Hemisphere where oceanic areas predominate.

5. CONCLUSION

The major impetus for this work has been the need to provide to the field user a quantitative cloud picture whose information would be preserved through the transmission and display process. To this end, we have developed a technique that has shown good agreement with ground truth data on amounts and heights of clouds and can produce output products well within the capacity of the user's display system to reproduce faithfully. The problems and errors of the system are probably no greater than that of the surface observation system, yet this system offers greater geographical coverage. The "thin cirrus" problem perhaps can be solved only by incorporating an additional sensor such as the 6.5- to 6.9- μ m water vapor channel on future satellites.

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